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## HIGH-G VERIFICATION OF LITHIUM-POLYMER (LI-PO) POUCH CELLS

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May 2016



U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND  
ENGINEERING CENTER

Munitions Engineering Technology Center

Picatinny Arsenal, New Jersey

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14. ABSTRACT Lithium cell battery technology continues to advance in power densities and dimensional characteristics as commercial markets continue their increased demand for smaller high-power density batteries. Such market factors enable projects to take advantage of the low cost and available power sources to meet the project's power needs. However, the market factors may also lead to product line cancellations causing re-evaluation of power sources. This report evaluates two types of lithium-polymer cells for use in high acceleration environments for telemetry systems supporting the design, development, and testing of smart and precision mortar and artillery projectiles.					
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## INTRODUCTION

Advances in electronics have enabled smaller and more powerful electronic devices to be developed as designers are able to package more capability in smaller spaces. At the same time, power requirements have increased, while available space has decreased. Smartphones today illustrate this trend, as they pack enormous computing power into small form factors and, at the same time, require tightly packaged power sources. The same is true for gun-launched telemetry systems for precision-guided munitions development. As mortar and artillery munitions are packaged with the latest fuzing, warhead, guidance and navigation technologies, the telemetry systems used during development have become equally advanced, while needing to maintain small form factors, making the choice of battery for such systems a challenge.

Choosing a battery for a gun-launched telemetry system boils down to answering three considerations. (1) It must be determined whether or not a particular battery, when arranged into a battery pack with a series and parallel combinations of cells, will provide the minimum voltage and current capacity, for the length of time required. (2) Next, it needs to be determined whether or not the system, more specifically, the battery pack will fit into the available space allocated for a power source. (3) It must be determined whether or not the battery is specific to gun-launched telemetry systems and if it will survive. Batteries used in such systems have the added requirement of needing to survive in spinning, high-g environments that are not experienced in most commercial applications.

Numerous commercial battery options are available with different sizes, capacities, and charge/discharge rates. Lithium batteries are one available option that comes in many form factors. In addition to traditional round cylindrical or button cells, battery manufacturers have been producing lithium batteries in prismatic or pouch cells to support growing power needs and enable greater flexibility of battery integration.

In this report, two different lithium polymer (Li-Po) pouch cells are evaluated for use in gun-launched telemetry systems. The power requirements of three existing telemetry systems are used to configure and evaluate each battery into a set of packs. The discharge characteristics of these packs are then tested in the laboratory, with results provided later in this report. The batteries are then subjected to spinning, high-g environments typical of gun-launched munitions. Air gun and live-fire test results are also provided later in this report.

## BATTERY CONSTRUCTION, REQUIREMENTS AND CANDIDATES

### Battery Construction

The Li-Po cells are prevalent in consumer electronics where small form factors are a necessity. Examples of different size Li-Po cells are shown in figure 1.



Figure 1  
Types of Li-Po battery pouches

The Li-Po cells are commonly sold with two metal tabs protruding from the foil pouch (typically one nickel and the other aluminum), prewired, or with a printed circuit board for terminating wires.

The Li-Po pouch batteries are constructed using multiple layers of laminated solid materials that are sealed in a foil pouch. This use of solid electrolyte lends this type of battery construction to be safer than constructions with liquid electrolytes. Photographs of this construction can be seen in figure 2.

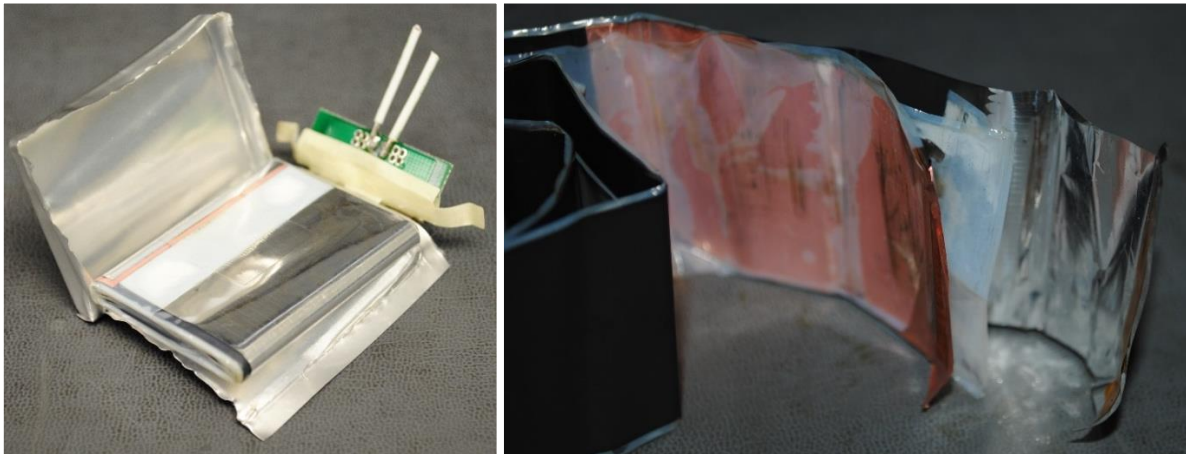


Figure 2  
Internal construction of a Li-Po cell

## Battery Candidates

For these telemetry systems, it is the size constraint requirements that drives the choice of battery. The batteries investigated in this study that meet the systems' power and size requirements are the Hyperion G3CX 240 mAh and Power Stream GMB052025 (also known as GM052025). Details of the batteries are listed in table 1.

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Table 1  
Manufacturer specifications

	<b>Hyperion Battery</b>	<b>GMB Battery</b>
Part Number	HP-LG325-0240-1S-M	GMB052025
Single Cell Nominal Voltage	3.7 volts	3.7 volts
Single Cell Capacity	240 mAh	180 mAh
Maximum Discharge Current	6A continuous (25C)	270 mA Continuous (1.5C)
Single Cell Dimension (mm)	30.6 x 20.2 x 6.3	26 x 20.5 x 5.2
Termination Type	Tabs or Wired	PCB or Wire
Selected For Telemetry System #	1, 2, 3b	3a

## Battery Requirements

The power requirements of three existing telemetry systems are used in this report to configure and evaluate each battery candidate and arrange them into a set of battery packs. There are four telemetry system specifications listed in table 2 entitled: Telemetry systems nos. 1, 2, 3a, and 3b. Telemetry systems nos. 3a and b have the same requirements with only a size constraint difference.

Table 2  
Telemetry system power requirements

<b>Power System Parameters</b>	<b>Telemetry System 1</b>	<b>Telemetry System 2</b>	<b>Telemetry System 3a &amp; 3b</b>
Nominal Voltage (volts)	7.4	7.4V	7.4V
System Load (mA)	1000mA	250mA	500mA
System Run Time	30 minutes	20 minutes	15 minutes
Size Constraint (mm) Diameter x Length	50.75 x 23	Ample	(a) 30 x 14.6, (b) 37 x 18
Acceleration Survivability	Threshold: Caliber 155mm: 15,000 g's		
Spin Survivability	Threshold 80 Hz; Objective: 300 Hz		

Many battery types, both commercial and military, could potentially be used to power these systems given their power requirements. For instance, in the radio controlled (RC) vehicle market, battery distributors offer battery packs that range in voltage from 3.7 V and beyond 14.8 V with capacities ranging from under 100 mAhs and beyond 5,000 mAhs.

## BATTERY BENCH TESTING

### Hyperion Battery Testing

#### Hyperion Single Cell Testing

A single cell discharge test of the Hyperion battery was conducted to establish a baseline discharge performance curve for the battery. The discharge plot is shown in figure 3. The battery was discharged at a constant current rate of 314 mA, which was removed when the voltage reached 2.8 V to prevent damage to the cell. A discharge time of 49.8 min was observed.

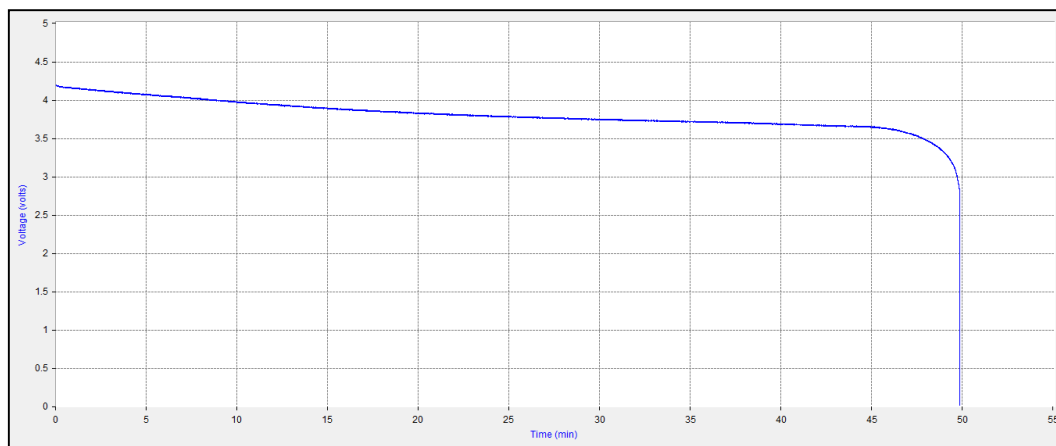


Figure 3  
Hyperion battery cell discharged at 314 mA

Placing two of these cells in a series configuration (also known as 2S configuration) will double the nominal voltage while maintaining the same capacity at the same current draw. Therefore, based on this single cell discharge, telemetry system no. 2 requirements are easily achievable and no further bench testing is necessary with only survivability testing to be verified.

#### Telemetry System No. 1 Bench Top Battery Testing

Placing battery cells in parallel typically doubles the capacity. Hence, using the Hyperion battery cells, a battery pack would need to have the configuration of two cells in series, and three sets in parallel (2S3P), in order to meet the power requirements of telemetry system no. 1. Such a battery pack was built and is shown in figure 4. It has an overall dimension of 30.6 by 20.2 by 37.8 mm, a nominal voltage of 7.4 V, a capacity of 720 mAh, and a maximum rated discharge of 18 A. This battery pack was subject to three cycles of bench top discharge testing, each at a successively higher constant current discharge level. The first cycle was at a constant current of 688 mA, which was removed when the pack voltage reached 5.7 V. Prior to the first discharge, and after each discharge test, the battery pack was charged with a Triton brand Li-Po charger set to 0.2 A as the maximum current. The resulting performance curve is shown in figure 5. A discharge time of 66.93 min was observed.

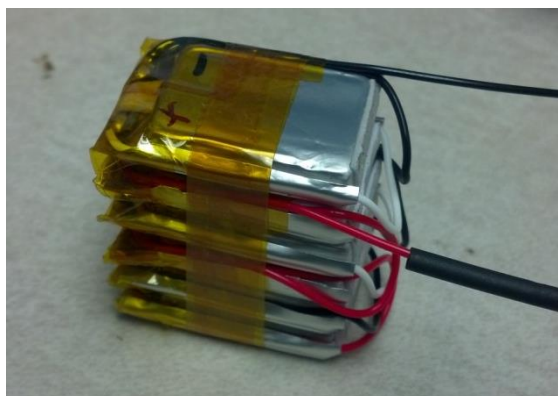


Figure 4  
Hyperion 2S3P stack

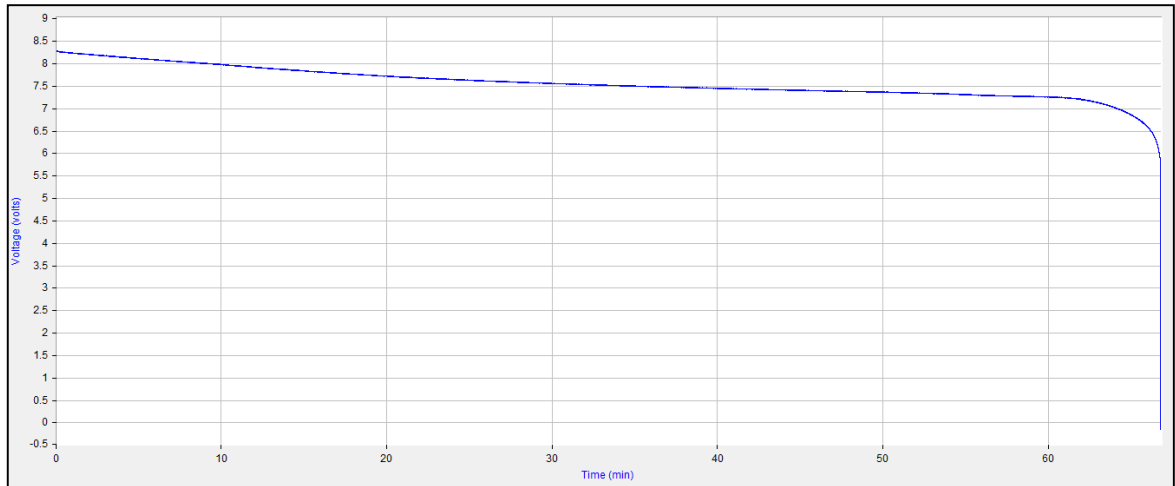


Figure 5  
Hyperion battery pack (2S3P) discharged at 688 mA

The Hyperion battery pack was recharged and was then discharged a second time, this time with a constant current load of 788 mA. The load was again removed when the pack voltage reached 5.7 V. The resulting performance curve is shown in figure 6. A discharge time of 56.7 min was observed.

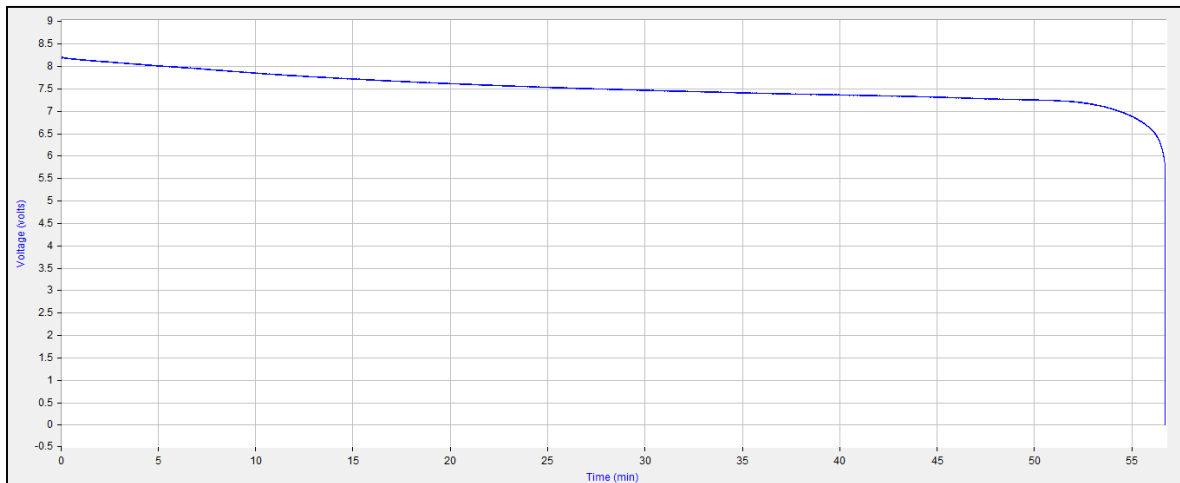


Figure 6  
Hyperion battery pack (2S3P) discharged at 788 mA

The Hyperion battery pack was recharged and was then discharged a third time, this time with a constant current load of 900 mA. The load was again removed when the pack voltage reached 5.7 V. The resulting performance curve is shown in figure 7. A discharge time of 49.58 min was observed. A summary of the discharge cycles is shown in table 3.

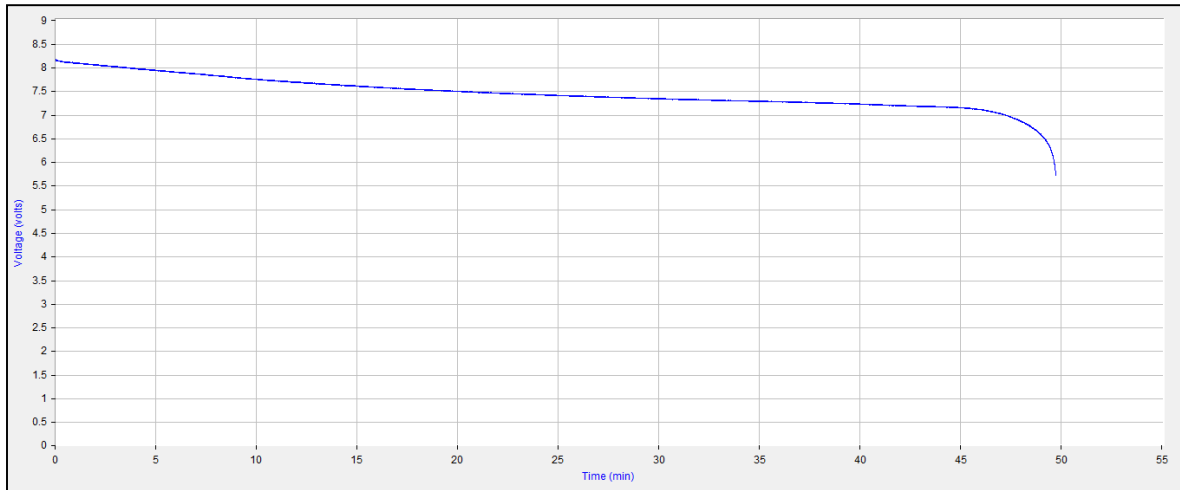
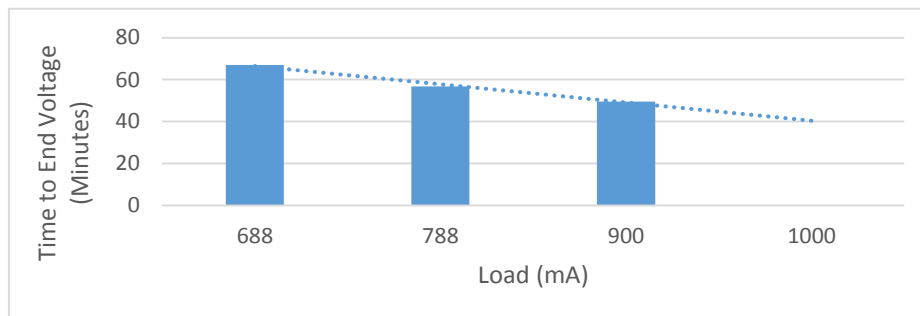


Figure 7  
Hyperion battery pack (2S3P) discharged at 900 mA

Table 3  
Hyperion discharge summary (2S3P configuration)

	Discharge 1	Discharge 2	Discharge 3
Load (mA)	688	788	900
Start Voltage (volts)	8.278	8.185	8.15
Starting Capacity (mAh)	744	735	743
End Voltage (volts)	5.7	5.7	5.7
Time to End Voltage (min)	66.93	56.7	49.58



Shown in table 3 is a chart of the discharge data with a linear trend line predicting the Hyperion 2S3P battery pack discharge time extrapolated a 1000 mA load, which is approximately 40 min.

While the power source shown in figure 4 does not meet the size constraint requirements of telemetry system no. 1, placing two stacks of cells, three tall side by side, would yield dimensions of 40.4 by 30.6 by 18.9 mm, meeting the requirement over six cells stacked on top of each other. Therefore, the Hyperion 2S3P configuration is assumed to meet the requirements of telemetry system no. 1 with survivability remaining to be verified.

### Guangzhou Markyn Battery (GMB) Co., Ltd Testing

The GMB batteries were not used as candidates for telemetry system nos. 1 and 2 and were only considered for telemetry system 3a.

#### Telemetry System No. 3A Bench Top Battery Testing

A single GMB battery cell has a rated maximum continuous discharge current of 270 mA, which is below the required current draw of telemetry system nos. 3a and 3b. However, the battery can still be used beyond its rating, since the telemetry system is a single use system and longevity of the components isn't a concern, and as long as its discharge performance is measured. Multiple discharge cycles were conducted to determine if this battery will be able to supply the current necessary to meet the telemetry system requirements.

A discharge of two cells in series (2S configuration) was conducted seven times to determine the discharge time of the batteries and to note any failures associated with the higher than rated discharge current draw. The results are shown in figure 8.

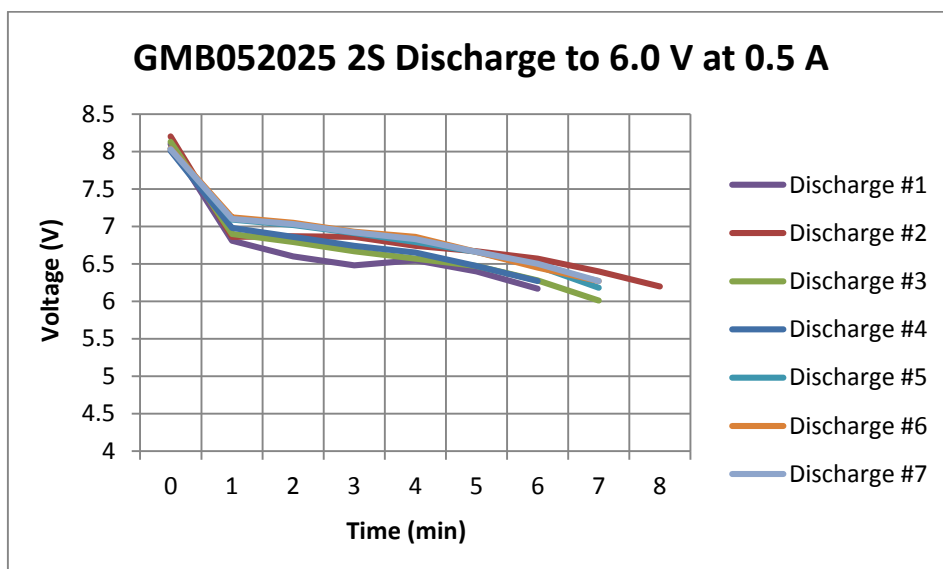


Figure 8  
GM052025 2S discharge characteristics

The batteries held an average of 6.33 V after 6 min. with no failures observed (such as overheating or a loss of capacity). Adding a parallel set of batteries should increase the discharge time of the batteries to nearly 15 min. Subsequent tests were performed to verify this assumption, as described in this report.

#### Telemetry System No. 3A Bench Top Battery Pack Testing

Four GMB battery cells were arranged together into a battery pack as a 2S2P configuration. In series with each 2S stack was a Schottky diode. The diodes act as a steering circuit; one stack failing short under set back does not cause the whole battery pack to fail short, at the expense of a small voltage drop by the diodes. Wires were available to charge and discharge each individual stack behind the diodes. The cells were then installed into an aluminum housing and wired to a connector as shown in figure 9.

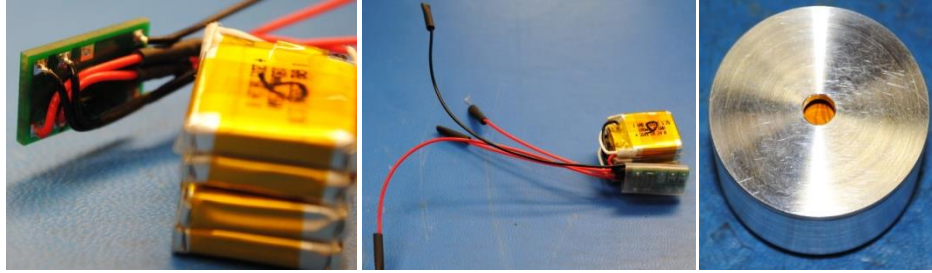


Figure 9  
Telemetry system no. 3a battery integration scheme

The pack was subject to four discharge cycles before high-g testing, as shown in figure 10. Each discharge performed with a constant current load of 521 mA (a Li-Po charger set to discharge) that was removed when the battery pack voltage reached 6 V. The pack was recharged between cycles with the Li-Po charger, set to 0.1A maximum current, except before the first discharge cycle with which the batteries were used from the factory where they are typically not shipped charged to full capacity. The pack was tested un-potted for the first and second cycles and potted in its housing using a two part filled epoxy resin for the third and fourth cycle.

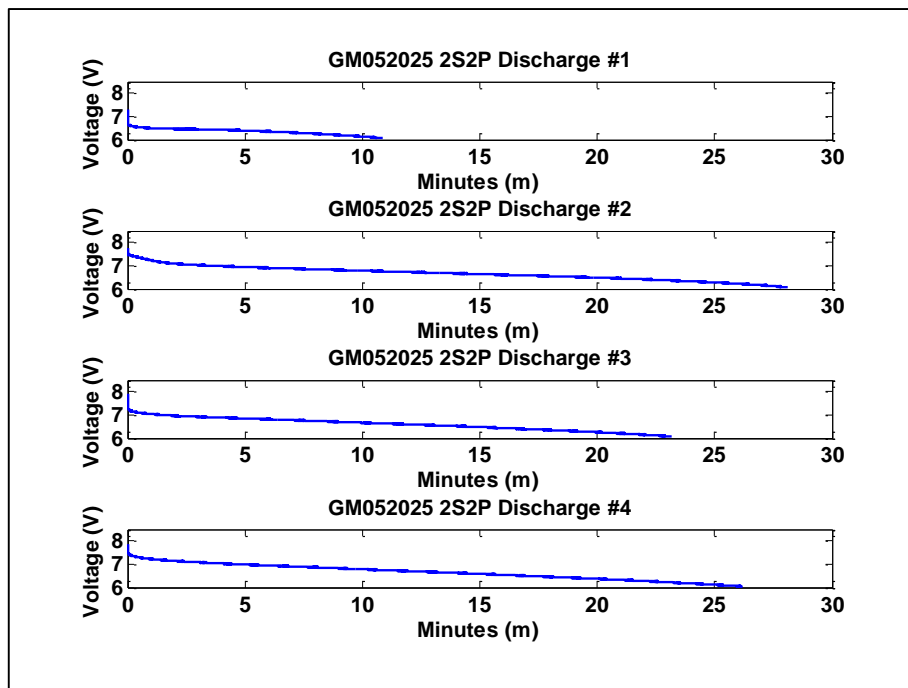


Figure 10  
Discharge plots of GM052025 battery pack in 2S2P configuration with diodes

### HIGH ACCELERATION BATTERY QUALIFICATION

In order for any new electronic component to be considered flight qualified, it must be tested under a spinning, high-g shock environment to ensure that it will survive gun-launch. For these telemetry systems, the batteries used must survive accelerations resulting from a 155-mm Howitzer firing Modular Artillery Charge System Zone 5 (MACS 5) propellant. This would yield approximately 15,000 G's depending upon final projectile weight, spinning up to approximately 300 Hz.

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Battery cells constructed as round cylindrical and button cells are supported by their metal casings, which reduce the flex and deformity of the battery under acceleration. However, pouch cell batteries do not have the same rigid casings. Therefore, to reduce the risk of flexing and deformation, battery pouches within gun-launched munitions should be laid flat so the pouch does not collapse upon itself on its edge. Additionally, the number of cells stacked on top of each should also be minimized to further eliminate the forces transferred from one cell to another. Finally, the battery pouch cells should also be encapsulated, providing a rigid structure and support for the batteries.

### Air Gun High Acceleration and Spin Testing

#### Guangzhou Markyn Battery Air Gun Static Testing for Telemetry System No. 3A

The same 2S2P battery pack used in bench testing was tested in the 155-mm air gun. A silicon controlled rectifier (SCR) monitoring circuit was developed that maintained a lit light-emitting diode (LED) unless current from the batteries dropped below 6 mA for 0.5  $\mu$ s or longer. The circuit drew 60 mA nominally while the LED was lit. A light guide protruded from the fuze housing containing this circuit so that status can be easily identified as shown in figure 11. Both housings were potted with a two-part filled epoxy resin as shown in figure 12.



Figure 11  
Telemetry system no. 3a battery verification circuit and integration

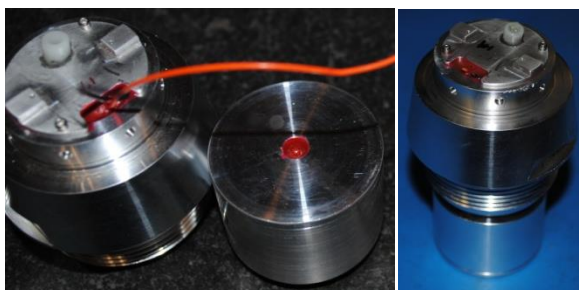


Figure 12  
Encapsulated telemetry system no. 3a battery test assets

A pretest voltage reading of 7.59 V was recorded from the battery pack. The system was turned on then loaded and fired in the 155-mm air gun with a 20,000 G's target acceleration. At a total projectile weight of 17.25 lb, the firing apparatus measured 18,110 psi of breech pressure and an axial acceleration at 20,997 G's. After 16:20 min passed, the LED was on (fig. 13) signifying zero battery drop out or connector disengagement. The battery was removed from the air gun tube after 19:06 min, and the voltage was measured to be 7.542 V. The air gun facility estimates a maximum spin of the projectile to be 86.6 H (ref. 1).

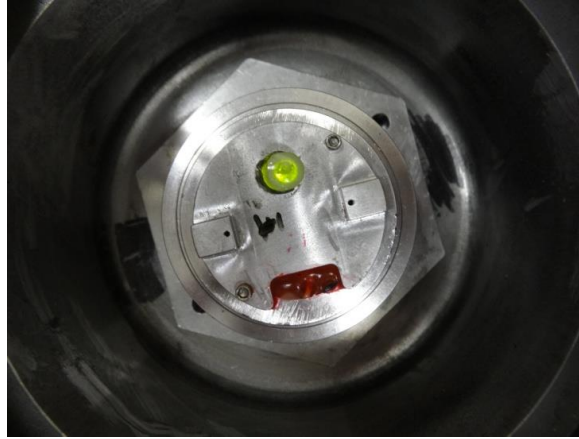


Figure 13  
Telemetry system no. 3a battery test asset post-test function

A second air gun test was conducted on a new GMB052025 2S2P battery pack, this time measuring pre and post-firing discharge rates. Each individual 2S stack (herein referred to as Stack A and Stack B) within the battery pack was individually charged, discharged, and charged again prior to air gun testing with a Li-Po charger set to 0.1A maximum. After air gun testing, each stack was individually charged and discharged again. Each discharge performed with a constant current load of 230 mA (a Li-Po charger set to discharge), which was removed when the battery pack voltage reached 6 V. The discharge plots of both the pre shot and post-shot cycles are shown in figure 14. A discharge time of 32:55 min was observed for Stack A pre air gun shot and 32:06 min post-air gun shot. A discharge time of 36:02 min was observed for Stack B pre air gun shot and 34:26 min post-air gun shot. At a total projectile weight of 17.22 lb, the firing apparatus measured 18,170 psi of breech pressure and an axial acceleration of 21,066 G's with a pre firing 2S2P pack voltage of 8.112 V and post-firing pack voltage of 8.00 V.

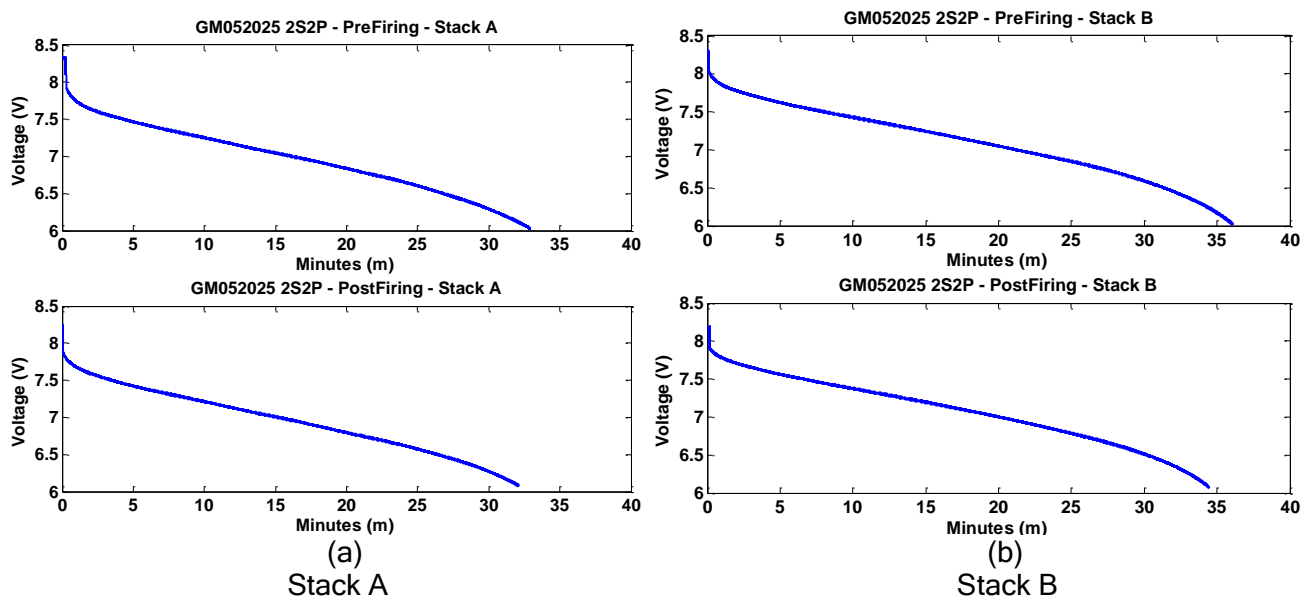


Figure 14  
Discharge plots within GM052025 battery pack in 2S2P configuration with diodes, pre and post-air gun firing

### Hyperion Battery Air Gun Static Testing for Telemetry System No. 3B

Three Hyperion 240 mAh 25 C batteries were combined into a battery pack in a 3S series configuration. Parallel with each battery was a reversed biased Schottky diode, which would act to bypass the battery should it fail. Extra wiring was not needed to charge the 3S stack as the diodes do not block the charging current as in the 2S2P GMB battery pack. The cells were then placed into an aluminum metal housing and wired to a connector as shown in figure 15.



Figure 15  
Telemetry system no. 3b battery integration scheme

Another copy of the same SCR monitoring circuit was used, which maintained a lit LED unless current from the batteries dropped below 6 mA for .05  $\mu$ s or longer. The system drew 60 mA as a load on the battery. A light guide protruded from the fuze housing containing this circuit so the status can be easily identified as shown in figure 16.

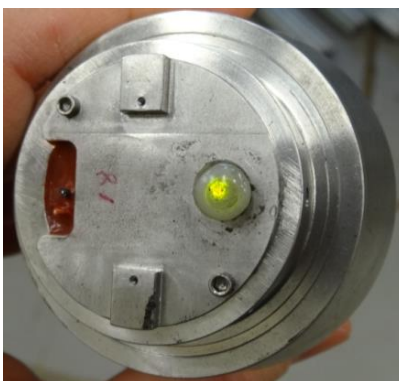


Figure 16  
Telemetry system no. 3b battery test asset post-test function

A pretest voltage reading of 11.53 V was recorded from the battery pack. The system was turned on, then loaded and fired in the 155-mm air gun with a 20,000 G's target acceleration. At a total projectile weight of 17.26 lb, the firing apparatus measured 18,120 psi of breech pressure and an axial acceleration of 20,996 G's. After 15:34 min passed, the LED was on (fig. 16) signifying zero battery drop out or connector disengagement. The battery was removed from the air gun after 20:08 min, and the voltage was measured to be 11.434 V. The air gun facility estimates a maximum spin of the projectile to be 86.6 Hz (ref. 1).

A second air gun test was conducted, this time measuring pre and post-firing discharge rates. The pack was subject to three discharge cycles pre high-g testing and one post as shown in figure 17. Each discharge was performed with a constant current load of 521 mA (a Li-Po charger set to discharge), which was removed when the battery pack voltage reached 9 V. The first discharge occurred when the cells were in the state from the factory, the second was charged prior with a Li-Po

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charger set to 0.2A maximum current, and the remaining discharges were charged prior with the Li-Po charger set to 0.1A maximum current. The pack was tested unpotted for the first and second cycles and potted in its housing with a two-part filled epoxy resin for the remaining cycles. Discharge times in minutes for the first, second, third, and post air gun shot cycles were 16:47, 28:02, 27:26, and 27:38, respectively. A small glitch is observed during the second discharge, speculated to be due to a momentary connector disconnect. For the air gun test, at a total projectile weight of 17.24 lb, the firing apparatus measured 18,070 psi of breech pressure and an axial acceleration of 20,962 G's with a pre firing 3S pack voltage of 12.514 V and post-firing pack voltage of 12.02 V.

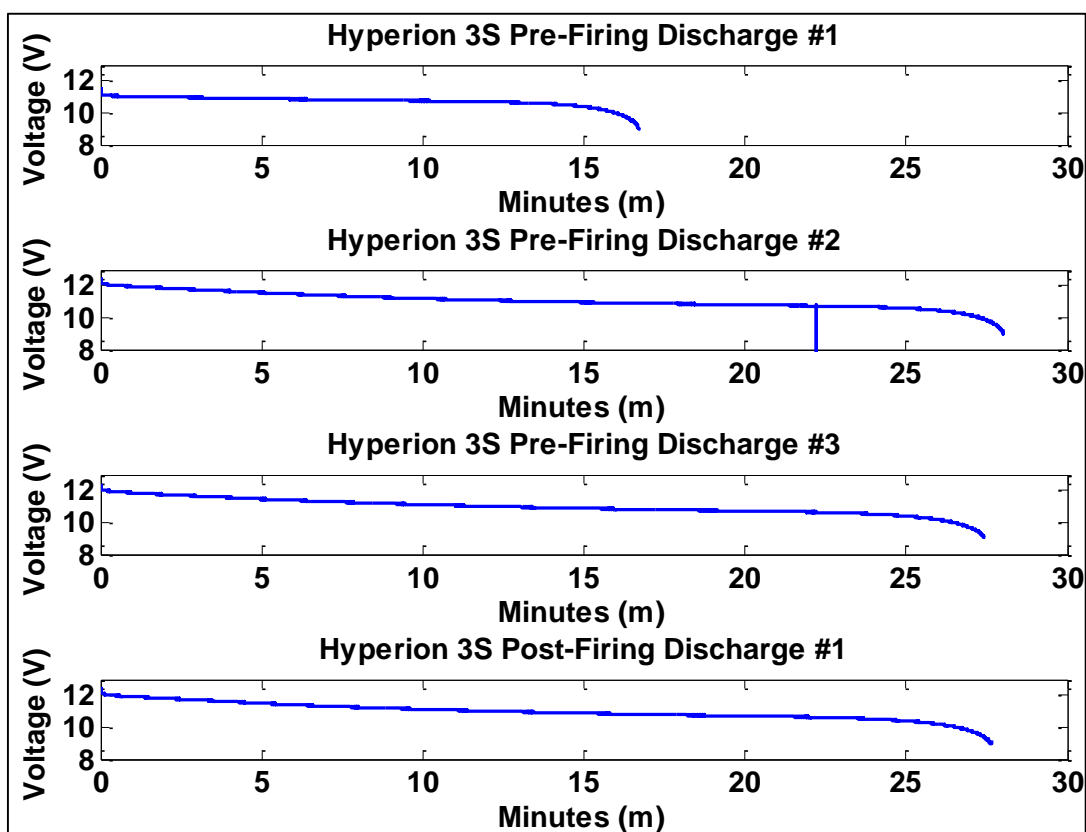


Figure 17  
Discharge plots of 3S Hyperion Batteries, pre and post-air gun firing

#### Follow On Guangzhou Markyn Battery Air Gun Testing for Telemetry System No. 3A

The GMB battery module that survived static testing was reused for dynamic load testing of telemetry system no. 3a in the air gun. At a projectile weight of 17.43 lb, the air gun measured a breech pressure of 7,420 psi. The GMB battery voltage as measured over time during set back acceleration is shown in figure 18 along with acceleration data from the on-board telemetry system, which recorded an axial acceleration of 7,018 G's. Note the axial acceleration was filtered with a second-order Sallen-key filter with a cutoff frequency of 1 kHz, and the battery voltage plot was filtered with a single-pole RC filter with a cutoff frequency of 2.5 kHz.

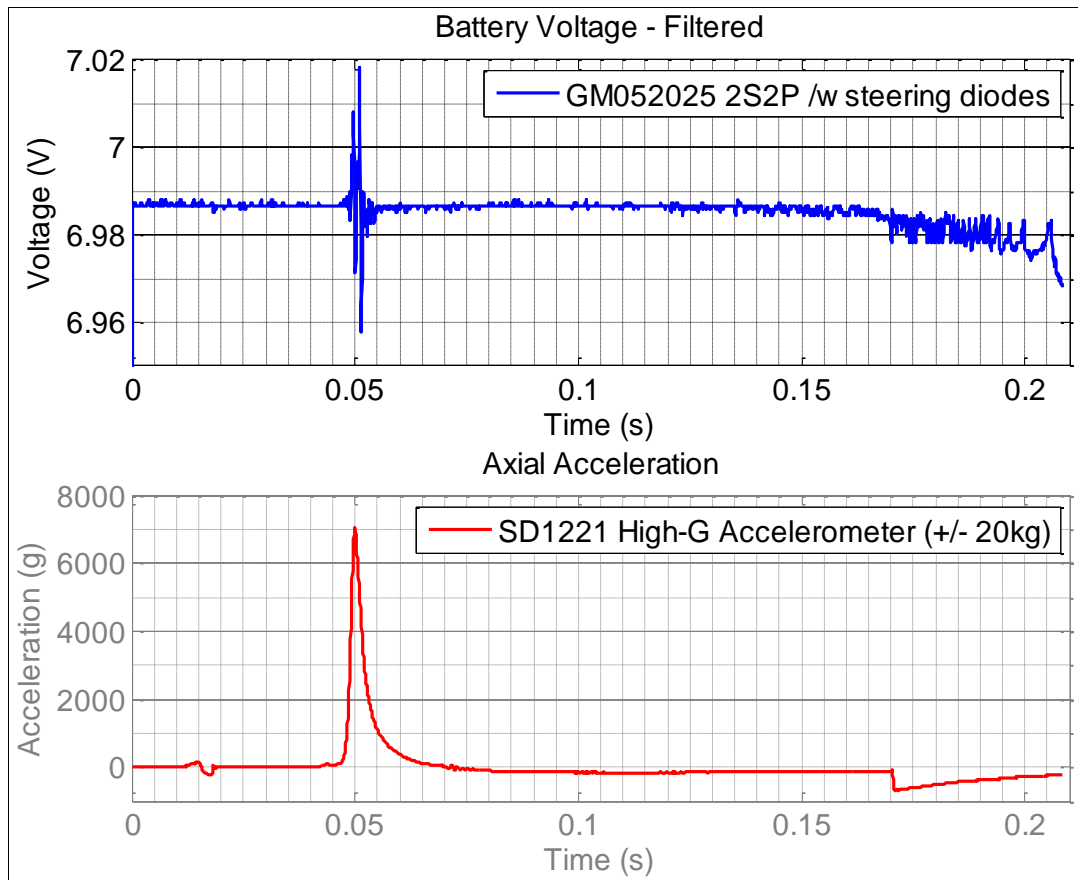


Figure 18  
Telemetry System no. 3a, GMB air gun battery and acceleration data

A transient voltage was seen during the set back phase of the acceleration with a minimum of 6.958 V and a maximum of 7.0175 for a 60 mV peak to peak total. As the projectile surged down the air gun's deceleration tubes, voltage transients reaching 10 mV peak to peak were observed. The batteries survived the spin environment of the air gun, which was measured by the telemetry system as between 71 and 76 Hz, depending on the sensors being evaluated. Spin measurements are shown in figures 19 and 20.

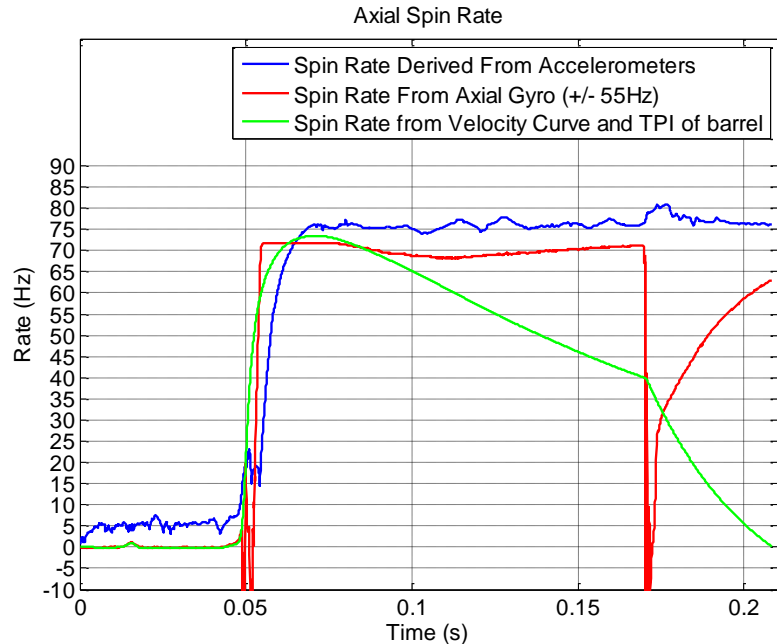


Figure 19

Telemetry system no. 3a, GMB air gun spin data from accelerometers and gyroscopes

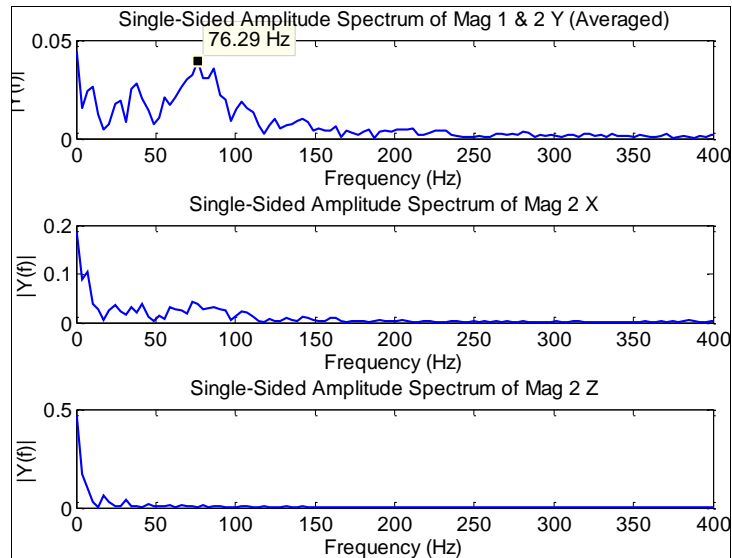


Figure 20

Telemetry system no. 3a, GMB air gun spin data from magnetometers (Fourier transform)

Based on these air gun tests, both the GMB and Hyperion cells achieved their minimum survivability requirements, qualifying them for howitzer test firings.

### Soft Catch (SCAT) Gun High Acceleration Testing

#### Hyperion Battery Soft Catch Gun Load Testing of Telemetry System No. 2

Two Hyperion 240 mAh 25C batteries were placed in series (2S configuration) with a single Schottky diode to protect the batteries from external power and encapsulated in a two-part

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filled epoxy resin within a stereolithography (SLA) fabricated plastic cavity. That cavity was then installed into a steel housing along with an on-board recorder with a triaxial Endevco 7270 A 60,000 G's range accelerometer, as shown in figure 21. The system was fully encapsulated in wax prior to testing.

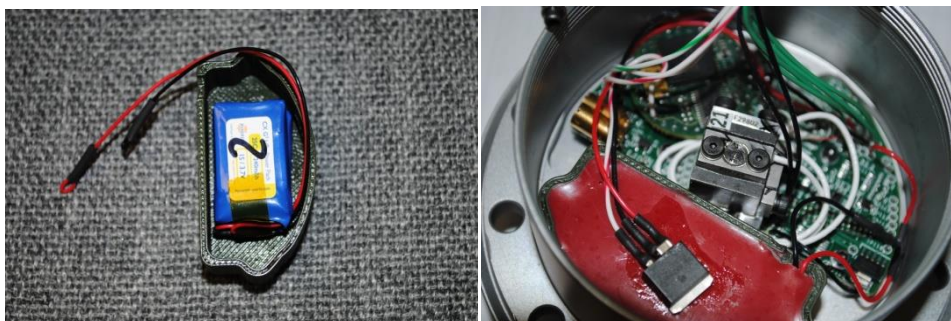


Figure 21  
Hyperion SLA and integrated steel housing

The batteries were fired under both electronic load and high acceleration environmental loading at the U.S. Army Armament Research, Development and Engineering Center's (ARDEC), Picatinny Arsenal, NJ SCAT gun. Telemetry system no. 2, serial no. 3, was fired in SCAT gunshot number 838 with an observed axial acceleration of approximately 11,700 g's with a projectile weight of 104.8 lb, fired at the U.S. MACS 5. Figure 22 shows the acceleration environment and battery voltage from the shot where the recording electronics used a 50 kHz anti-aliasing filter. An approximate voltage drop of 33 mV was seen during the set back phase of acceleration and about 60 mV during set forward.

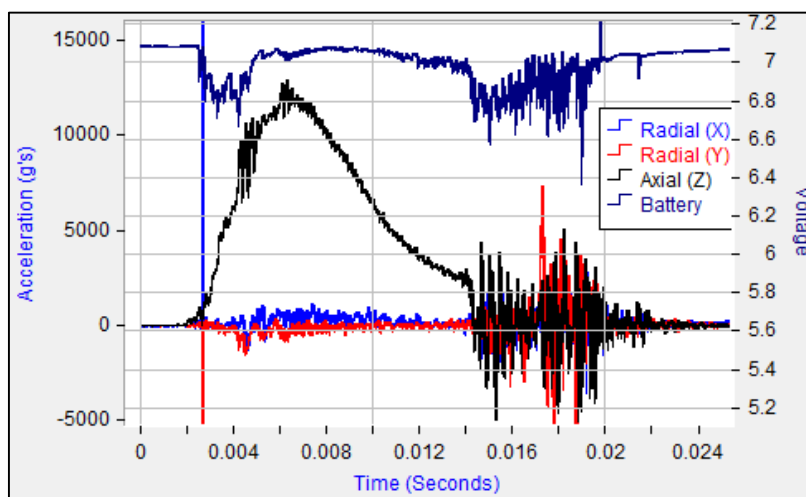


Figure 22  
Telemetry system no. 2, 2S SCAT gunshot no. 838

## Tactical Weapon High Acceleration and Spin Testing

### The Guangzhou Markyn Battery Tactical Weapon Testing for Telemetry System No. 3A

After successful air gun testing, telemetry system no. 3 was qualified on a M795 spotter round on a M777 Lightweight 155-mm Howitzer at Yuma Proving Grounds, Yuma, AZ [YPG, (ref. 2)]. The battery voltage measured during the set back and set forward high acceleration events

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is shown in figure 23. Note the axial acceleration was filtered with a second-order Sallen-key filter with a cutoff frequency of 1 kHz, and the battery voltage plot was filtered with a single-pole RC filter with a cutoff frequency of 2.5 kHz.

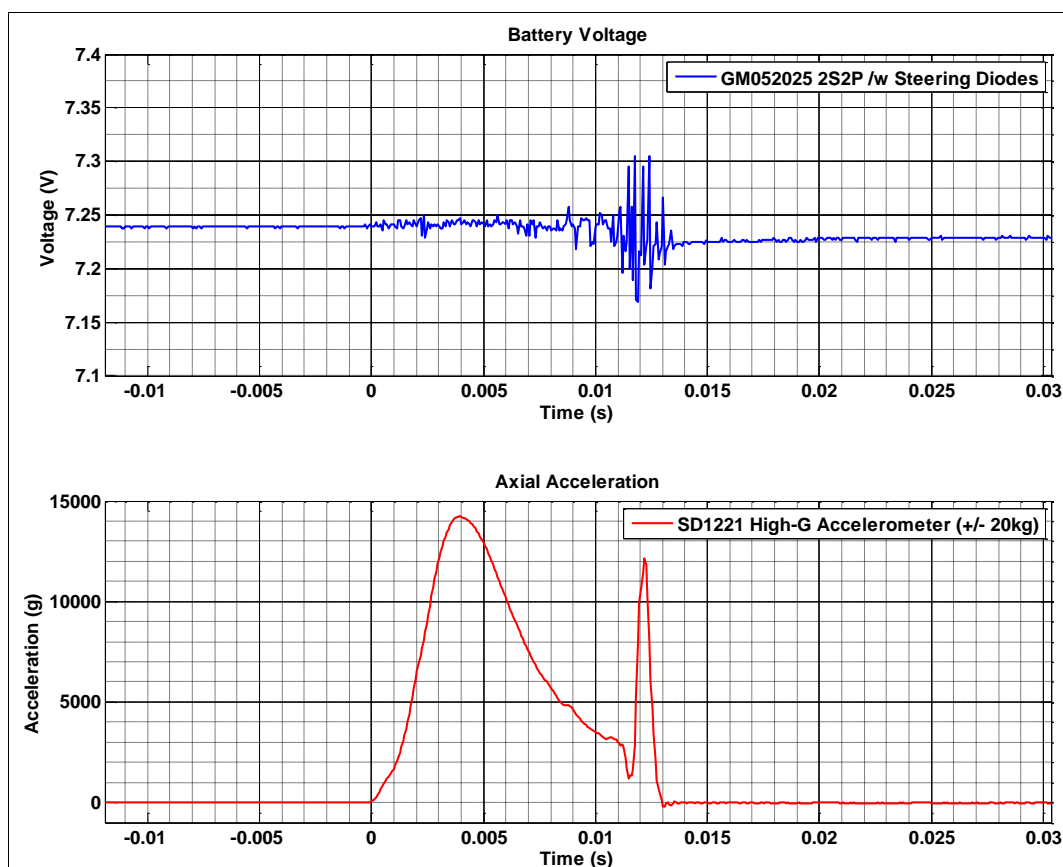


Figure 23  
Telemetry system no. 3a, GMB M777 acceleration and battery voltage

With an estimated peak acceleration of 14,200 G's and 260 Hz of spin, with slight oscillations during set back and greater amplitude oscillations during set forward (0.1 V), the batteries rebounded and maintained a voltage above 7.2 V throughout flight. Note that the set forward high-g acceleration seen in figure 23 does not fully represent the muzzle exit environment. Many factors impact this, including but not limited to the sensor frequency response, device sampling, and filtering. For the purpose of this report, figure 23 provides data points for peak acceleration and location of muzzle exit seen by the projectile.

Also measured by telemetry system no. 3a was the battery voltage and temperature of the system, while the M795 Projectile was in flight, as shown in figure 24. Starting at 10 sec after firing, the on-board temperature sensor measurement began to increase from 25° to 42°C by the end of flight, 51 sec later. Starting 15 sec after firing, the battery voltage increased gradually from 7.21 to 7.27 V by the end of flight. It was expected for battery voltage to drop while under load but not to rise, which may be explained by the rise in temperature. It is noted that the spin rate also was decreasing from 237 to 199.4 Hz during the time of flight, which may have contributed to the unexpected voltage rise. Aeroballistic heating of the projectile is speculated as being the cause of the temperature rise (ref. 2).



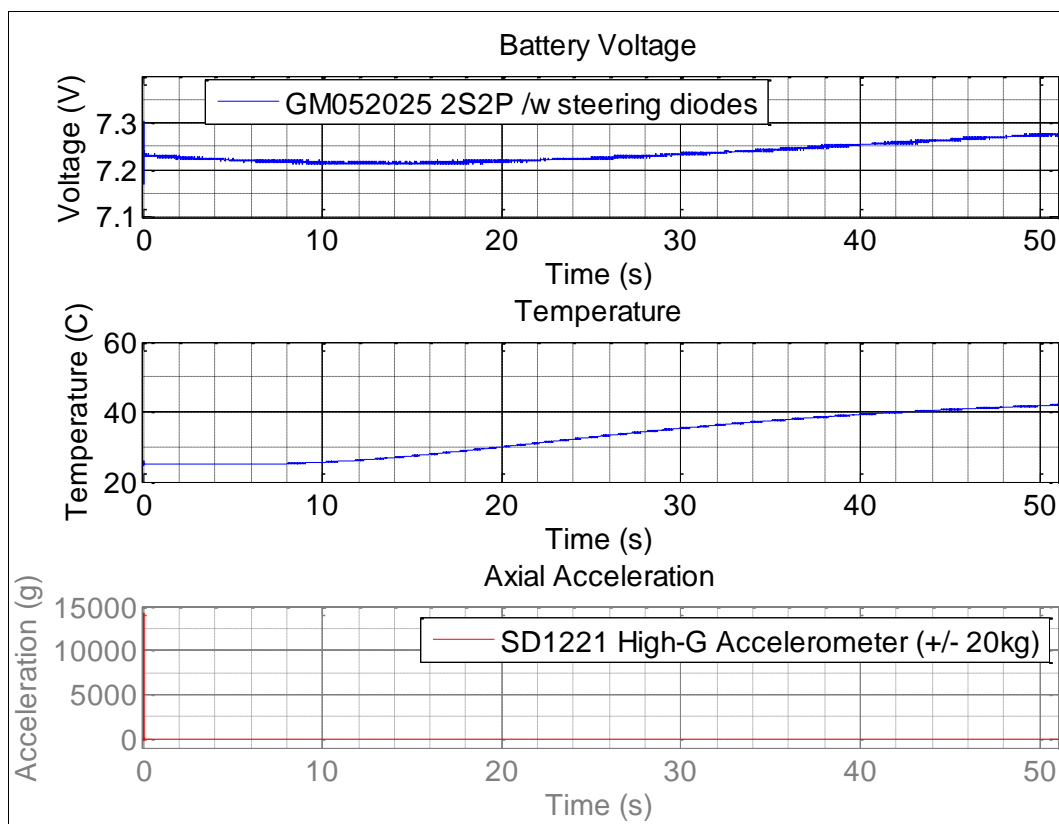


Figure 24

Telemetry system no. 3a, GMB M777 battery voltage, temperature, and axial acceleration

### HIGH ACCELERATION VOLTAGE DROP DISCUSSION

Voltage drops during high acceleration events are a common occurrence for lithium batteries. Burke, Bukowski, Newnham, et al. (ref. 3) experienced 1 V drops on a 16 V system during shock table testing of lithium batteries during battery prototype development in May 2000. In June of 2009, Bukowski reported (ref. 4) on his evaluation of cylindrical lithium cells that CR123 cells were not able to withstand the ballistic environments necessary for their telemetry systems and that CR2's experienced a 50 mV voltage change during shock table testing. He recommended their use below a 35,000 G shock environment and up to 225 Hz to achieve battery performance without any degradation.

In this report, three separate testing environments captured battery voltage transients resulting from set back and/or set forward events from ARDEC's air gun, SCAT gun, and tactical weapon testing at YPG. A summary of the reported results is shown in table 4. The discussion following the table evaluates Li-Po performance with respect to its composition, regardless of manufacturer, and assumes a similar battery construction despite their physical and electrical differences.

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Table 4  
Testing environment and battery transient summary

Platform	Acceleration (g's)	Spin (Hz)	Voltage Transient (mV P-P)	Acceleration Rise Time (ms)	Set Back Duration (ms)	Set Forward Duration (ms)
Airgun (GMB)	7,000	76	60 @ Set Back	1	4	Transients Not Observed
Airgun (Hyperion)	Not Measured During Firing	< 86.6*	Not Measured During Firing			
SCAT Gun (Hyperion)	11,700	< 30*	33 @ Set Back 60 @ Set Forward	4	12	6
Tactical Firing (GMB)	14,200	260	22 @ Set Back 100 @ Set Forward	4	11.5	1.5
* Not Measured, based on historical or theoretical data.						

From the data plotted in figure 22, the SCAT gun caused a voltage drop before transients were observed during both set back and set forward acceleration phases. Additionally, although the set forward duration and associated acceleration transients are a harsher environment than that of the tactical firing shots (ref. 5), the recorded battery voltage was similar to that of the tactical firing. From this data, the conclusion can be drawn that the set forward and catch tube environments the SCAT gun induces on projectiles under testing do not negatively impact Li-Po cell performance.

Conducting a subsequent SCAT test closer to the acceleration level of the tactical firing would provide a greater data point comparison of the voltage transients during set back and set forward for each manufacturer of battery. Telemetry system no. 2 used in the SCAT gun test also exhibited greater transients than expected. Additional work to determine any cross talk on the data lines should also be conducted.

## CONCLUSIONS

Battery voltage transients are common during high acceleration testing events and coincide with set back and set forward events. Power systems should be designed to withstand these transients to prevent temporary power brown outs, and testing of lithium pouch batteries in their stacked array should occur to ensure expected performance.

In the cases of the aforementioned telemetry systems, both models of batteries (Hyperion 240 mAh 25C and GMB052025) were observed to meet the performance requirements of their respective telemetry systems used for this report. Also, given that these batteries are readily available from commercial-off-the-shelf sources, it indicates that production is continuing for these model lines. These low cost available power sources will enable telemetry engineers to continue their support to smart and precision mortar and artillery development projects with reliable power sources that enable the collection of vital interior and exterior ballistics data.

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